BELLCOMM, INC.
955 L'ENFANT PLAZA NORTH, S.W. WASHINGTON, D.C. 20024

B70 07048

SUBJECT: Lunar Exploration Modes
Case 105-4

DATE: July 16, 1970

FROM: C. L. Davis

ABSTRACT

An analysis has been performed to establish the number and types of mission modes that could possibly be used for future manned lunar exploration. Excluding those that are logically impossible yields 20,000. Further considerations based on current studies and opinion reduces the range to between 120 and 4 viable mission modes.

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MEMORANDUM FOR FILE

INTRODUCTION

In the course of the past decade, and more, many particular means of exploring the moon have been postulated and examined in addition to the mode used for Apollo. Variables such as earth orbit rendezvous, lunar orbit rendezvous, lunar surface base, cislunar shuttle and many others produce a proliferation of possibilities. The analysis presented here is intended to systematically develop all the possible modes by simply considering the combinations of all the variables, and the state each variable may be in. This analysis is followed by a speculative consideration of the impact of current studies.

DISCUSSION

The Apollo mission profile serves well to establish the character of this analysis. The vehicle departs the earth surface (ES), resides briefly in earth orbit (EO) for targeting purposes, transfers to lunar orbit (LO) for targeting purposes, a portion separates and descends to the lunar surface (LS) and then returns to LO for rendezvous with the portion remaining in LO, and finally the system returns directly to ES. This can be schematically written as,

$$ES \rightarrow EO \rightarrow LO \rightarrow LS \rightarrow LO \rightarrow ES\ .$$

In this case the vehicle does not rendezvous with any previously established vehicles at any location (EO, LO, or LS). It is a completely self contained mission. However, the rendezvous of the CSM and LM in LO does impose a constraint which is not made evident by the schematic representation.

Consider now the system developed in the integrated plan. In this case men, equipment and propellants were delivered to the nuclear cislunar shuttle (CLS) in EO by the space shuttle. It was implicitly assumed that the CLS was loitering in the vicinity of a space station and propellant storage facility. The men, equipment and some propellants were transferred by the CLS to a permanent lunar orbit station. Subsequently the men descended to the LS, either to a fixed lunar surface base, or to a particular site for a brief exploration mission. The sequence was simply reversed to return to ES. This process is schematically shown as,

$$ES \rightarrow EO \rightarrow LO \rightarrow LS \rightarrow LO \rightarrow EO \rightarrow ES$$

This appears quite similar to the Apollo profile but there are profound distinctions in the operations due to the particular EO and LO required by the permanent orbiting facilities and the choice of landing sites on the moon, either the fixed base or some other site that is unconstrained in latitude and longitude. Because of these properties the sequence should be rewritten as:

$$ES(p) \rightarrow EO(p) \rightarrow LO(p) \rightarrow LS(t,p) \rightarrow LO(p) \rightarrow EO(p) \rightarrow ES(p)$$

With these examples as background we can move on to a more rigorous approach.

DEFINITIONS

There are six locations in the cislunar system that are believed important to establishing this analysis. These locations are ES, EO, LO, LS, HEO* and HLO*. The last two are high energy intermediate orbits that might be used in a staged reusable transportation system. For example HEO might be a highly elliptical orbit about the earth. These terms are defined as follows;

- ES - Earth surface, generally taken as KSC, the fixed launch site.
- EO - Earth orbit, implicitly taken as a low altitude earth orbit, about 100 to 300 n.m.
- HEO - Earth orbit, but defined as being high energy such as geosynchronous or a two day elliptical orbit with a 200 n.m. perigee.
- LO - Lunar orbit, implicitly taken as a low altitude lunar orbit, approximately 100 n.m. circular.
- HLO - Lunar orbit, but defined as being high energy such as might be used in conjunction with HEO.
- LS - Any point on the lunar surface.

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*HEO = high earth orbit.
*HLO = high lunar orbit.

Any of these six locations can be in one of four states;

1. not part of the mission, signified by o.

2. A temporary or transient part of the mission that does not result in a rendezvous constraint, but does impose trajectory constraints, signified by e.

3. A temporary or transient and self contained part of the mission that results in trajectory and rendezvous constraints, as does LOR in the Apollo mission profile, signified by t.

4. A permanent state as represented by a space station, propellant facility, surface base or other device that places a strict constraint on the flight profiles of all missions, signified by p.

ANALYSIS

If we now write the general schematic equation for this system it appears as;

$$\begin{aligned}
&ES(o,e,t,p) \rightarrow EO(o,e,t,p) \rightarrow HEO(e,o,t,p) \\
&\rightarrow HLO(o,e,t,p) \rightarrow LO(o,e,t,p) \\
&\rightarrow LS(o,e,t,p) \rightarrow LO(o,e,t,p) \\
&\rightarrow HLO(o,e,t,p) \rightarrow HEO(o,e,t,p) \\
&\rightarrow EO(o,e,t,p) \rightarrow ES(o,e,t,p)
\end{aligned}$$

A few examples will help to clarify this. The Apollo mission is written as,

$$ES(p) \rightarrow EO(e) \rightarrow LO(t) \rightarrow LS(t) \rightarrow LO(t) \rightarrow ES(t).$$

A direct mission with a pause in lunar orbit on the outbound leg to permit wider site selection might appear as,

$$ES(p) \rightarrow LO(e) \rightarrow LS(t) \rightarrow ES(t).$$

The general equation provides the means for enumerating all of the possible mission modes. Before doing that there are a few simple rules that must apply and that reduce the number of possibilities.

1. All modes must begin with ES(p). That means that a fixed launch site is being considered.

2. All modes must end with either ES(p) or ES(t). That is we may demand return to a fixed point, the p state, or a restrained set of sites, the t state, as in Apollo.

3. Since we are interested in surface missions LS must appear in all modes, thus the o state is not permitted. Furthermore the e state is meaningless since the purpose of the missions is lunar exploration and thus the landing site is fundamentally constraining. Therefore LS may exist in the t or p states only. It should be noted that a system capable of LS(t), where t represents any logitude and latitude, will include LS(p) since access to any fixed point will always be possible.

4. There are special constraints on the states that LO may assume as it appears on both sides of LS. These are as follows;

Outbound LO States

Inbound LO States	o	e	t	p
o	√	√	x	√
e	√	√	x	√
t	x	x	√	x
p	√	√	x	√

√ = allowed

x = not allowed

The t state is the only constraining state. That arises because the t state requires rendezvous, on the inbound leg, with a vehicle left in orbit on the outbound leg. Thus it is inherently incompatible with any other state. The other states o, e & p can concievably mix with each other on inbound and outbound legs.

5. The matrix giving the constraints on inbound and outbound LO states applies equally to the pairs of inbound and outbound EO, HEO, and HLO states.

6. The only constraint concerning the states of adjacent positions is that, for return, ES must be in the p state if the return state of EO is e, t or p since one would only stop in EO on the return to achieve landing at a fixed site. Conversely ES will be in the t state if EO is in the o state on return.

The general equation now appears as;

$$\text{ES(p)} \rightarrow \text{EO} \rightarrow \text{HEO} \rightarrow \text{HLO} \rightarrow \text{LO} \rightarrow \text{LS(t,p)} \rightarrow \text{LO}$$

$$\text{HLO} \rightarrow \text{HEO} \rightarrow \text{EO} \rightarrow \text{ES(t or p)},$$

and notes 4, 5 and 6 apply.

This equation permits 20,000 possible mission modes and at this point we have not yet even considered the alternative mechanization issues such as chemical vs. nuclear propulsion or aerobraking on return to earth orbit.

COMMENTS

Obviously one does not deal with 20,000 alternatives. There are studies in course which will diminish the number of cases, as will certain pragmatic constraints. The following notes are indicative of the expected impact of current activities.

The use of a lunar orbit station appears likely for a mixture of reasons, should this be the case then LO(p) is the only state for lunar orbit. On the other hand attractive missions can be constructed using LOR but not requiring a lunar orbit station. These missions are represented by LO(t). There does not appear, at this time, to be any attractive missions using LO(o,e). Then we may speculate that LO will only assume the t and p states, which reduces the number of permissible inbound to outbound LO cases from ten to two. (See note 4, page 4)

The space shuttle demands the use of EO as an assembly orbit, but operations analyses point to mixed advantages associated with the EO(p) state. On the other hand rendezvous is required since numerous space shuttle flights are necessary to mount a single lunar mission. Then EO(t) is the probable state but EO(p) cannot be eliminated. Other studies, not premised on the current space shuttle concept, as proposed by Orrok (Reference 1), require the use of the EO(e) state, and may require EO(t). At this time there are no known studies showing the EO(o) state to be attractive, although it may well be. Then the following EO states appear probable; EO(e,t,p).

Use of the HEO and/or HLO modes leads to operational efficiencies but may require the development of additional vehicles. This situation appears unlikely though possible. One study by Lockheed proposes the use of ES → EO → HEO → LS etc. Another study by Ehricke (Reference 2) proposes permanent stations at EO, HEO and LO, as part of the transportation net. Then it is probable that HLO will not be used (i.e., HLO(o)) and further that if HEO(o) on the outbound leg then HEO(o) on the inbound leg. Then, although HEO may take on any of the four state values (o,e,t,p), there are only six sets of acceptable inbound and outbound HEO values as opposed to the ten shown in the table on Page 4.

Finally, the return to earth must be to ES(p), since the state of EO will be either e, t, or p, but not o.

Should all these speculations materialize the mission mode equation finally appears as;

ES(p) → EO(e,t,p) → HEO(o,e,t,p)

→ LO(t,p) → LS(t,p) → LO(t,p) → HEO(o,e,t,p)

→ EO(e,t,p) → ES(p)

It turns out that this equation, when constrained as discussed above, represents 120 mission modes. That certainly represents an improvement of 20,000, but it is still too high. The EO pairs represent 5 choices and the HEO pairs 6 choices. Then future analysis should be concentrated on the reduction of EO and HEO state values.

Further speculation based on early analytical results, indicates that EO will always be in the e or t states, HEO in the o state, LO in the t or p states and LS in the t state, this latter including p state capability. If these speculations materialize then there are only four important mission modes to examine. These four are listed on the attachment.

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C. L. Davis

REFERENCES

1. G. T. Orrok, "A Cislunar Shuttle", Memorandum for File, Bellcomm, Inc., April 14, 1970.

2. K. A. Ehricke, "A Strategic Approach to the Development of Geolunar Space," North American Rockwell, SD69-710, October, 1969.

ATTACHMENT

Equation

ES(p) → EO(e,t) → HEO(o) → HLO(o) → LO(t,p)
→ LS(t) → LO(t,p) → HLO(o) → HEO(o)
→ EO(e,t) → ES(p).

(o state terms dropped from the equations.)

Mode I

ES(p) → EO(e) → LO(t) → LS(t)
→ LO(t) → EO(e) → ES(p)

Mode II

ES(p) → EO(t) → LO(t) → LS(t)
→ LO(t) → EO(t) → ES(p)

Mode III

ES(p) → EO(e) → LO(p) → LS(t)
→ LO(p) → EO(e) → ES(p)

Mode IV

ES(p) → EO(t) → LO(p) → LS(t)
→ LO(p) → EO(t) → ES(p)

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